Working Paper

Potential Effects of Emission Taxes on CO_2 Emissions in OECD and LDC Countries

Sabine Messner and Manfred Strubegger

WP-90-77
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Foreword

Increased research effort is being directed worldwide toward formulating appropriate measures and policies for reducing energy-related sources of global warming. In view of the scientific uncertainties a consensus is emerging that such measures and policies must be based on precautionary principles by limiting and ultimately reducing future sources of greenhouse gases. This involves both the reduction of emissions and reduction of potential impacts and effects of increased atmospheric concentration of greenhouse gases.

This paper by Sabine Messner and Manfred Strubegger presents an important contribution to this research effort by analyzing the potential consequences of energy-related carbon emission taxes in two world regions—the OECD and developing countries. This comparative analysis is based on the formulation of two alternative scenarios with the energy systems optimization model MESSAGE III: One serves as a reference scenario and is based on market clearing prices and the other introduces carbon emission taxes in the two world regions. The environmental tax is set at \$46 per ton of carbon dioxide in the OECD countries but is lower in the developing countries. This is somewhere in between the values commonly given in the literature and is high enough to cause significant changes in the structure of the energy system toward more efficient and cleaner technologies and thus result in a reduction of energy-related emissions. A 50 percent increase of carbon dioxide emissions compared with 1990–levels in the reference scenario that is based on market clearing prices is turned into a near stabilization of future emissions to 1990–levels by the year 2020 through the introduction of carbon taxes. However, the effect and consequences of carbon taxes are different in the two world regions. In the OECD countries the carbon taxes have an almost immediate effect on improving the efficiency of the energy system and causing a shift toward "low-carbon" fossil fuels (natural gas) and carbon-free sources of energy. In the developing countries, a relative reduction is also achieved but in absolute terms the carbon emissions increase in both scenarios illustrating that the carbon taxes alone are likely to be an insufficient instrument for achieving global greenhouse emissions stabilization to current levels. The carbon taxes cause substantial increase in required investment, especially in the developing countries where the need for additional capital would compete with other investments required for growth and development.

The paper indicates the magnitude and complexity of global tradeoffs and important equity issues implicit in the pervasive adoption of carbon taxes and many other greenhouse gases reduction policies. The analysis demonstrates that the assumed carbon taxes are insufficient as a sole instrument for stabilizing carbon dioxide emissions and therefore it indicates the need for more robust policies that tie-in different measures for reduction of greenhouse gases emissions. Many measures are in fact cost-effective and worth doing on their own right. In the long run positive effects of energy efficiency improvements, conservation and a general shift toward clean and less carbon intensive energy sources such as gas would benefit both developed and developing countries provided that appropriate institutions are created to help master the economic and technological challenges. In the broader context, the paper also illustrates the difficulty of stablizing and eventually reducing global carbon dioxide emissions and the critical interlinkages between population growth, economic development, energy use, and environmental quality.

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Potential Effects of Emission Taxes on CO_2 Emissions in OECD and LDC Countries

Sabine Messner and Manfred Strubegger

Abstract

A set of existing optimization models representing the energy systems of the OECD and LDC[1] countries with a time horizon up to 2020 was applied to derive first-order estimates of the techno-economic potential for emission reduction. The driving force for the introduction of reduction measures was a scheme of taxes levied on the emissions of 6 relevant pollutants—including the greenhouse gases CO_2 and methane. The tax levels introduced are based on the taxes discussed by the Swedish government administration; they are the break-even point to test which measures are cost-effective and which emission levels can be reached at these costs.

The regional models offer the choice between the following alternatives as response to increases in expenditures caused by emission taxes:

- Reduction of final energy demand by supplying the requested services by other means (i.e., conservation).
- Substitution of "dirty" fuels by fuels entailing less pollution.
- Introduction of "clean" technologies for the same purposes (e.g., a combined cycle based on coal gasification is a much cleaner process for electricity generation from coal than conventional coal power plants).
- For SO_2 and NO_x emissions pollution reduction technologies (i.e., scrubbers and catalysts) can be added to existing technologies in order to reduce emissions.

Alternative scenarios with emission taxes are compared to a Base Scenario without taxes related to pollutant emissions.

The results indicate that an increase in CO_2 emissions in the OECD and LDC regions of 47% over the next 30 years in the Base Scenario would be changed into stabilization up to 2010 by measures induced by the tax levels introduced. Thereafter, however, energy consumption growth in the LDC area, in conjunction with the exhaustion of economically viable emission reduction measures, reverse this trend: CO_2 emissions start to increase again after 2010.

[1]The LDC region covers all less developed countries excluding centrally planned economies.

1 Introduction

Human activities interfere with the natural environment in many different ways. Some activities, like agriculture or housing construction, evolved over the history of mankind, deliberately changing and reshaping the natural environment. Others, like deforestation in the Mediterranean, and currently in many developing countries, or the accumulation of chemicals generated by human activities in the atmosphere, are side-effects of economic development and industrialization. For most of our history the consequences of human activities have been confined to local effects enforcing, in case of major damages to the environment, changes in lifestyle or migrations to other areas. In any case, natural events like the Little Ice Age that started some 600 years ago or major eruptions of volcanos, had consequences at least in the same order of magnitude.

Industrialization rendered the capability for large-scale intervention in natural processes: burning fossil fuels, energy carriers with a high energy density, permits large unit sizes for production processes and a degree of urbanization unknown before. But it also gave rise to a unique threat to our societies: Carbon dioxide, product of any process burning hydrocarbons, might, together with other chemicals, be responsible for the postulated change in climate generally labeled greenhouse effect or global warming.

The Intergovernmental Panel on Climate Change (IPCC) was set up in 1988 to analyze issues related to man-made climate change and give advice to policy makers. Working Group 1, that is concerned with the scientific assessment of climate change, estimated the contribution of CO_2 to the total radiative effect from 1980 to 1990 to be in the order of 55% (IPCC, 1990a). The other contributors are: methane (15%), CFCs (24%) and nitrous oxides (6%). The major share (some 75%) of man-made CO_2 emissions are caused by energy conversion activities, i.e., burning of fossil fuels for electricity generation, in industries, private households and for transport. The remaining quarter relates to deforestation.

If the two important propositions of the IPCC (1990b) hold, namely that:

1. "There is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be," and that

2. "Emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases, ... (which) will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface."

then cost-effective strategies to reduce the emissions of all greenhouse gases will be required to limit and to forestall global warming.

Technology-oriented energy models are very instrumental in the analysis of potential pollutant emissions connected to various energy supply strategies. Existing models can be used to assess the potential of what Robert M. White (1990) labels "no-regrets initial policy steps": options to reduce CO_2 emissions that entail additional benefits or are readily available and economically viable, like energy conservation, efficiency improvements, substitution of natural gas for coal and oil or oil for coal and investment in non-fossil energy sources like nuclear or solar energy. Rightly White states that such measures "will not solve the climate-warming problem," but they will provide the basis for further actions.

The analysis presented in this paper uses a set of energy optimization models that encompass the whole OECD and LDC area (excluding centrally planned LDC countries like China)[2] that can be used to estimate the potential for reducing the emissions for CO_2 and other pollutants by introducing a tax on all activities related to emission of these chemicals. Other pollutants, like SO_2, NO_x and methane are included in the analysis to get a balanced picture of energy-related environmental issues: In the developing regions air pollution problems can be expected to increase in significance over the coming years, mainly due to short-term planning horizons and financial shortages in most of the developing economies.

Since the models used in the analysis are cost-minimizing they will, out of the menu of technologies available to supply energy service requirements, and taking into account the additional costs incurred by the taxing scheme, provide a consistent, cost-optimal path to supply the desired energy. All means to reduce CO_2 emissions being economical under the tax regime chosen will be used in this path. The regional models include all options listed by White (1990) with the exception of nuclear energy, which, considering present public resistance, may only contribute a limited share of electricity in all model regions and, as a consequence, cannot be expanded to technically and economically feasible levels.

Options exogenous to the energy system, like adding carbon sinks or afforestation, are not represented in the present version of the models used in the analysis. Such additional options could well come into focus to prevent further increases of CO_2 concentrations during the next century, when conventional methods cannot bring about acceptable CO_2 concentration levels. Presently and probably for a long time to come these levels and the related emission levels for greenhouse gases are the focus of scientific debate; consequently, there is no known target that we could try to reach with all types of measures, however costly they might be. This was the reason to choose the taxing approach and not apply limits on the emissions: it tells us, which measures are cost-effective at a certain tax (or cost) level.

2 Methodology and Model Structure

The analysis applies the scenario approach: the driving variables of energy demand, population and GDP development are, through assumptions concerning the evolution of sectoral energy intensities and lifestyle parameters, converted into energy service or useful energy requirements (hereafter simplifying called demand). This demand is one of the driving forces of the energy model used. The second important set of input parameters are the prices of internationally traded energy carriers. Together, they drive the solution of the energy model, i.e., the energy carriers used to cover energy service/useful energy requirements and the technologies necessary to provide and utilize these energy carriers.

In the development of a scenario a consistent set of parameters concerning the development of energy demand and energy import/export prices have to be evaluated. This approach was taken to derive the Base Scenario, which provides the reference case for the analysis described here: The Base Scenario is consistent with respect to regional energy demand development and international energy trade prices. This consistency was derived by a market clearing mechanism, introduced to determine the market prices of single energy carriers. For additional sensitivity analyses the regional energy models incorporate the option to adapt demand development to price changes (or other forces driving consumption down). This option can partly be interpreted as price-elasticity, and partly as conservation by investment measures (e.g., better insulation, more efficient equipment at

[2]The set of energy optimization models was developed and used recently for a global analysis of the competitive situation of OPEC oil in the international energy markets (Rogner, 1990).

higher cost).

The technologies represented in the energy models are dynamic with respect to the change of technical and economic parameters over time: they include an autonomous improvement of technology. The potential impacts of scenario assumptions, like cost reductions for solar technologies due to enhanced research activities accelerating technological improvements, are exogenous to the model. In this relation the statement given by Hogan and Jorgenson (1990) with respect to economic modeling, that "over this long horizon, the common economic modeling assumption of ... exogenous technological change, becomes progressively less tenable" can be considered equally valid for our techno-economic approach. In further analyses of long-term prospects of CO_2 emissions and possible reduction strategies, technological change has to be included as a parameter in the development of the scenarios: not only effects, but also causes of technological change have to be endogenized in the scenario definition.

2.1 The Energy optimization model

The computer model used for the regional models, MESSAGE III (Messner and Strubegger, 1990), is a dynamic linear programming model optimizing a given objective function (in this application the sum of the discounted costs of supplying energy over the next 30 years). It is a techno-economic model covering all physical energy flows, capacity requirements (including, e.g., peak production and back-up requirements in the electric system) and conservation measures with a very high degree of detail. Investment decisions and fuel choices are based on the cost-effectiveness, long-term demand development and requirements for replacing old capacities.

Structurally each of the regional models covers the total energy system from domestic resource extraction and energy imports via central conversion, transport, transmission and distribution of energy up to final consumption in various sectors of the economy, for transport and in private households. Energy demand is given in terms of useful energy for all thermal processes, in ton- or person-kilometers for transport and as final energy for the remaining, non-substitutable uses of energy (mainly coke in steel production and electricity for non-thermal uses). Consequently the model will choose an optimal strategy to use the available sources of energy and corresponding technologies based on the existing structure of the energy system, costs of energy supply, and requirements for infrastructure. It will search for the optimal path for introducing new technologies and phasing out uneconomical or not sustainable supply options. Since energy utilization and conservation measures are included in the optimization, optimal strategies will concern the overall energy system and include optimizing the structure and level of final energy consumption.

Additionally to mere modeling of the energy system as such, environmental and sociopolitical components of energy supply and consumption are included in the model structure: The regional models account for emissions of some of the important pollutants; they also include abatement measures for SO_2 and NO_x and "clean" technologies (e.g., fluidized bed combustion of coal) as alternatives in the menu of technologies.

Emissions of the following chemicals are accounted for in all conversion steps of the energy chain:

- Carbon dioxide (CO_2),
- Carbon monoxide (CO),
- Methane (CH_4),
- Nitrous oxides (NO_x),
- Sulphur dioxide (SO_2), and
- Non-methane volatile organic compounds (NMVOC's).

Examples of socio-political constraints include limits on the introduction of nuclear energy and on the share of domestic energy consumption covered by imports.

3 Basic Scenario Assumptions

The analysis is based on a set of models describing the energy systems of 6 world regions covering the OECD and the less developed countries (LDC's).[3] The major development work for these models was done between summer 1989 and spring 1990. Due to uncertainties in the future path the centrally planned economies will take and the still very limited availability of data these countries are excluded from the analysis. The time horizon starts in 1990 and extends to the year 2020.

As already stated in the section on "Methodology and Model Structure" the energy scenarios are based on assumptions concerning energy demand development and the expectations concerning the market clearing prices of internationally traded energy.

3.1 Economic development and energy demand

Table 1 shows the historical development and assumptions for the future growth of population, GDP and the resulting growth of GDP per capita for the OECD region and the LDC's.

The figures on population growth are taken from the UN Data Bank, the GDP development is based on an IIASA scenario (Rogner *et al.*, 1990). GDP growth for the LDC's is assumed to be higher than in the OECD area, which is principally in line with historical developments. However, the degree of discrepancy might exaggerate the development potential in the countries concerned: while the OECD economies grow at an average rate of 2.2% per year over the model horizon, the growth in the LDC's is assumed to be 4% per year. On the other hand, on a per capita basis the growth in the LDC's is only 0.3% per year higher than in the OECD area (2.11%/year versus 1.83%/year in the OECD).

The path assumed for future developments is also worth mentioning: The scenario is based on the expectation, that in the immediate future economic growth will be relatively moderate and, in comparison to historical rates, declining, with a reversion of this trend after the turn of the century.

The scenario presented includes a high degree of conservation compared to historical rates. While analyses of historical trends show that primary energy consumption per unit of GDP declines by 1% per annum (Nakićenović, 1989) indicating a low degree of

[3]The following regions were modeled separately: North America, West Europe, OECD Pacific, Latin America (excluding OPEC members), OPEC and other developing countries excluding centrally planned economies.

Table 1: Annual growth of population, GDP and GDP per capita, 1900–2020, in % per year.

%/yr	Population OECD	Population LDC's	GDP (real) OECD	GDP (real) LDC's	GDP/capita OECD	GDP/capita LDC's
1900–1950	0.88	2.20	2.28	2.77	1.38	0.55
1950–1973	1.15	2.46	4.72	5.32	3.52	2.80
1973–1987	0.76	2.50	2.52	4.41	1.74	1.87
1987–1990	0.54	2.52	3.47	3.07	2.91	0.54
1990–1995	0.53	2.42	2.07	3.94	1.53	1.49
1995–2000	0.48	2.29	1.64	3.96	1.15	1.63
2000–2010	0.36	2.04	1.99	4.11	1.63	2.02
2010–2020	0.17	1.42	2.69	4.22	2.51	2.75

Table 2: Final energy use per capita and per unit of GDP, 1987–2020.

	Final energy use per capita [kW/cap] OECD	capita [kW/cap] LDC's	unit of GDP [kWh/US$(87)] OECD	unit of GDP [kWh/US$(87)] LDC's
1987	4.30	0.56	2.53	6.06
1990	4.54	0.57	2.46	6.10
1995	4.52	0.59	2.27	5.86
2000	4.37	0.60	2.07	5.51
2010	4.23	0.67	1.70	5.02
2020	4.45	0.79	1.40	4.53

decoupling, the scenario presented here assumes a stronger degree of decoupling for the OECD region, rising from a reduction of final energy use per unit of GDP of 1.6% per year between 1990 and 1995 to 1.9% per year after 2010 (see *Table 2*). The LDC's are assumed to approximately follow the rate of 1% per year. The reasoning for these assumptions, which go beyond historical experience, is the expectation of increasing social awareness concerning the global environmental problems connected to energy consumption in the developed world.

Table 2 highlights another problem inherent to international development discrepancies in the North-South perspective: the relative inefficiency of the developing economies in terms of energy use per unit of GDP (nearly 2.5 times the use in the OECD area) and, on the other hand, the extremely low energy use per capita (the difference is more than a factor of 7). Due to the high population growth, even the favorable economic growth assumptions of the scenario do not allow a reduction of the gap between the developing and developed world: On a per capita basis, OECD citizens still consume 5.6 times more energy than the population of the LDC's in 2020.

An analysis of the per capita GDP of the two regions shows another effect of the same problem: historically the discrepancy between the developed and the developing world grew (see *Table 3*). The assumptions in the scenario reverse this trend and assume a very moderate narrowing of the gap. However, from a factor of nearly 20 today, only a

Table 3: Development of per capita GDP in absolute terms, 1900–2020.

	OECD	LDC's	factor
	US$(87)/cap		OECD/LDC's
1900	2.65	0.25	10.6
1950	5.26	0.33	16.0
1973	11.67	0.62	18.8
1987	14.87	0.81	18.4
1990	16.20	0.82	19.8
1995	17.48	0.88	19.8
2000	18.51	0.96	19.4
2010	21.76	1.17	18.6
2020	27.88	1.53	18.2

Table 4: International market clearing prices in 1987 US$ per barrel of oil equivalent.

US$87/boe	1987	1990	1995	2000	2010	2020
Crude oil	18.1	16.0	18.2	20.1	25.8	25.8
Natural gas	14.1	12.0	13.7	14.1	18.1	18.1
LNG	16.2	14.4	16.4	15.1	19.4	19.4
Coal	9.4	8.0	9.1	9.0	12.3	11.6

difference of a factor of 18 is reached by 2020.

3.2 International energy prices

Assumptions concerning the international market clearing prices for the globally traded energy carriers are consistent with the low energy demand growth expectations: From the low price in the beginning of 1990 they increase until a value of roughly 26US$(87)/boe is reached in 2010, stabilizing thereafter (see *Table 4*).

The prices of hard coal, natural gas imported via pipeline and LNG is the result of a market clearing mechanism of these prices versus the price of crude oil. It is noteworthy that natural gas and LNG cannot reach oil parity, the gap between the prices increases slightly. Clearly this is a consequence of the moderate demand growth in the scenario, where competition between the energy carriers is strong.

4 Model Results

Here we limit the description of the achieved, energy-related results to the structure of primary energy consumption. Thereafter, environmental aspects are shortly discussed for all pollutants considered, with a more detailed analysis for CO_2. Finally, impacts on investment requirements are discussed.

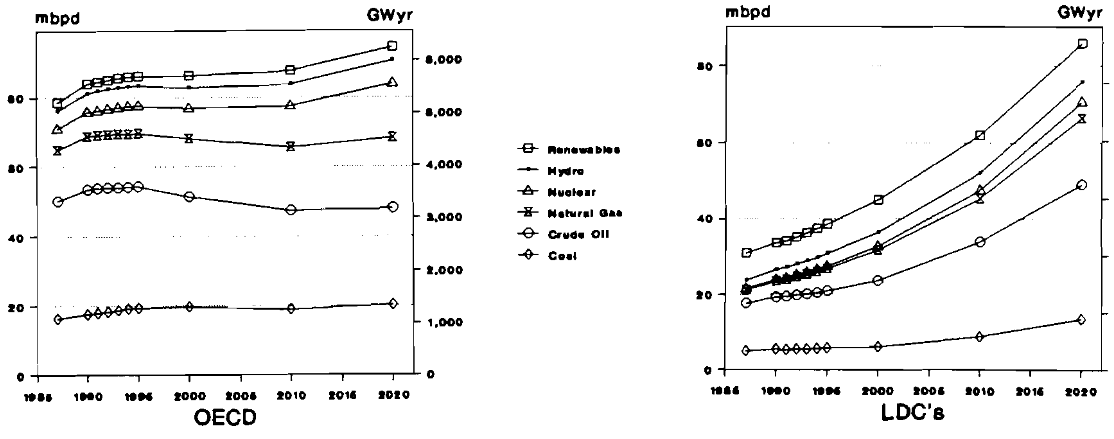

Figure 1: OECD and LDC's: primary energy consumption, Base Scenario, in million barrels of oil equivalent per day.

4.1 Base scenario

Primary energy consumption in the OECD countries reflects the envisaged pattern of economic development: after a period of moderate growth rates up to the turn of the century consumption growth accelerates after 2010 (see *Figure 1*). The contribution of coal increases to 20 million barrels of oil equivalent per day (mbpd), which is reached by 1995, then it stabilizes at this level. Crude oil and oil products contribute more than 40% up to 1995, thereafter oil's share in total energy consumption declines to 30% in 2020 being increasingly confined to transportation requirements. The gap left by declining oil use is filled by nuclear energy and natural gas, with gas covering an additional 5 mbpd by 2020 and nuclear energy growing from presently 7 mbpd to over 15 mbpd in the year 2020. The contributions of hydroelectric energy and other renewable sources of energy grow moderately at rates of 0.7%/yr and 1.3%/yr, respectively.

In comparison, primary energy use of the LDC's is much more dynamic: total primary energy consumption grows from 31 mbpd in 1987 to 86 mbpd in 2020, at an average annual rate of 3.2%. Coal and crude oil keep their market shares over the whole horizon, while natural gas can increase its share from presently 12% to 18% in 2000 and 20% in 2020. Nuclear energy grows moderately to 5% of primary energy in 2020, while hydropower and the other renewable sources of energy loose market shares. This does not mean a decline in absolute terms: they still grow from 9.5 mbpd today to 15.3 mbpd in 2020, i.e., at an average annual growth rate of 1.6%.

Figure 2 shows the pollutant emissions related to the Base Scenario. They are plotted as index related to the first year of the analysis. Emissions in the OECD are relatively stable, mainly due to the moderate growth in energy use and the relatively stringent standards with respect to SO_2 and NO_x emissions. Only the emissions of methane, the second most important greenhouse gas, increase slightly above the current level, while carbon dioxide emissions remain at current levels. This is an effect of the substitution of oil products by natural gas and nuclear energy. All other pollutants accounted for decrease in relation to present emission levels (carbon monoxide: –16%, sulphur dioxide: -21%, nitrogen oxides: -9% and NMVOC's: -21%).

As expected, the situation in the LDC's is much less favorable. Emissions of all accounted pollutants grow; the minimum increase is by 28% within 30 years for carbon

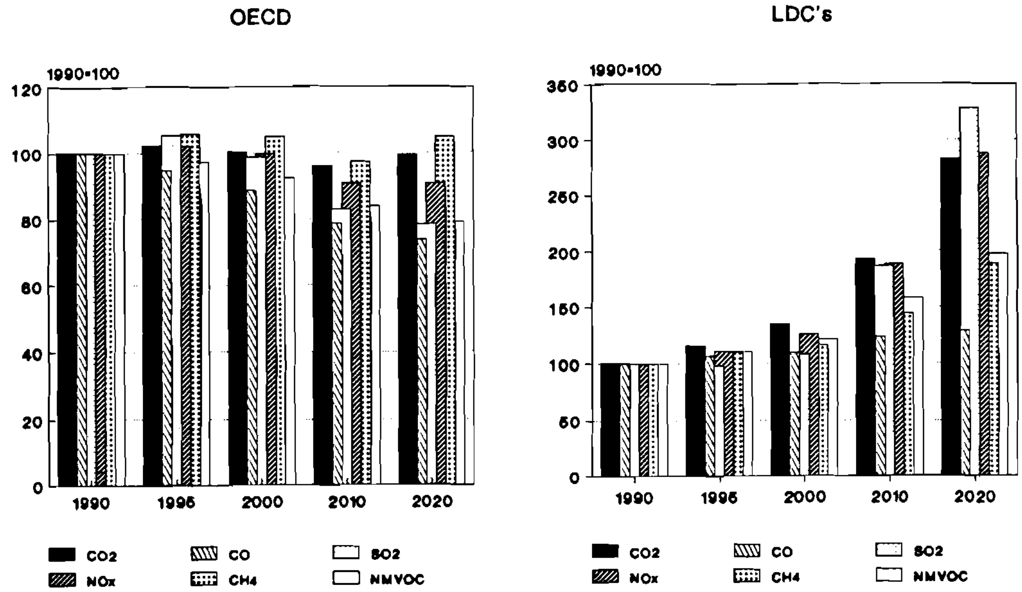

Figure 2: OECD and LDC's: pollutant emissions, Base Scenario, index (1990=100).

monoxide, a growth of 0.9%/yr. Emissions of the other pollutants grow at rates between 2 and 4% per annum. The highest increase can be seen for SO_2, which, by 2020, grows to more than 3 times the level of today. An explanation of the background of this Base Scenario is appropriate here: Pollutant emissions in the course of energy conversion and use are assumed to meet present standards in the modeled regions.[4] This means that no abatement measures are included for the LDC's. For the calculations with environment taxes separate technologies representing desulfurization and denoxing in the power generation sector and for industrial consumers are included in the models. These are selected in the optimization procedure if they are cost-effective versus the taxes on emissions.

4.2 Environment taxes

The Base Scenario served as a basis to simulate the effect of introducing emission taxes in an optimizing, rational environment. The taxes adopted for the OECD are based on those considered by the Swedish government administration (see *Table 5*). For the LDC's the values were divided by 2, giving credit to the relatively higher strain such taxes pose on developing economies, also due to the presently lower environmental standards and higher emission levels for some of the pollutants.

In their analysis based on the Global 2100 Model, Manne and Richels (1990) determine a long-run equilibrium tax of \$250 per ton of carbon, which is equivalent to \$68 per ton of CO_2, while Nordhaus (1989), who calculates shadow prices for greenhouse gases for various damage functions, comes up with \$3 to \$37 per ton of CO_2 equivalent.[5] Compared to these values the tax of \$46 per ton of CO_2 used in our model analysis seems to lie somewhere in between the values commonly given in the literature.

Compared to the Base Scenario the primary energy mix of the OECD countries reflects the higher awareness with respect to environmental problems: overall energy use is

[4]The emission data are based on the emission data bank compiled by the Parliamentary Inquiry Commission on "The Protection of the Atmosphere" of the Federal Republic of Germany.

[5]Nordhaus includes *all* greenhouse gases in his analysis, which is not possible in purely energy-related models, which, per definition, cannot include CFC emissions and abatement measures.

Table 5: OECD: Emission taxation, in US$(87)/kg of pollutant emitted.

Pollutant	Tax on emission
Carbon dioxide (CO_2)	0.046
Carbon monoxide (CO)	2.3
Sulphur dioxide (SO_2)	2.3
Nitrous oxides (NO_x)	2.3
Methane (CH_4)	0.23
Non-methane volatile organic compounds (NMVOCs)	0.23

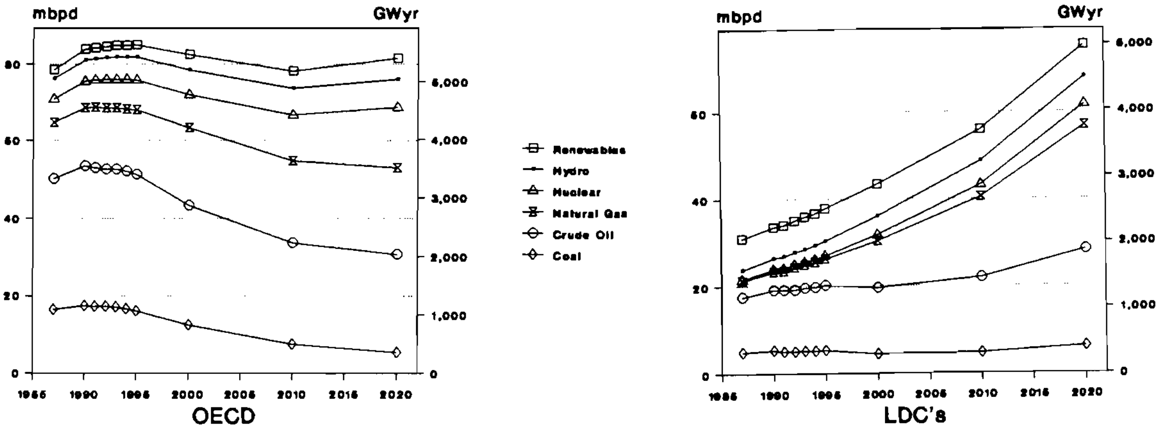

Figure 3: OECD and LDC's: primary energy consumption, Emission Taxation, in million barrels of oil equivalent per day.

some 15% lower (an effect of conservation measures), the contribution of coal is reduced to roughly 5% of primary energy by 2020 (see *Figure 3*). The use of liquid fuels is slightly lower than in the Base Scenario, natural gas increases its share by 2 mbpd. The contribution of nuclear power is not increased due to built-in constraints reflecting present acceptance problems of this energy source. Hydro-power and the other renewable sources of energy can increase their market share. By 2020 they contribute over 15% of primary energy (compared to 11% in the Base Scenario).

Due to the lower charges for pollutant emissions and the lower elasticity of energy consumption in the LDC's total primary energy use is only 12% below the Base Scenario, i.e., there is less conservation in the LDC's than in the OECD countries. The contribution of coal is reduced to half the value of the Base Scenario, but compared to present values there is still a growth from 4.8 mbpd to 6.1 mbpd in 2020. With 8% of primary energy use in 2020 the contribution of coal is also higher than in the OECD. Crude oil is also used to a much lower extent, while the contribution of hydro-power and nuclear energy is increased slightly in this scenario. The major increase, however, is in the use of natural gas: 29 mbpd compared with 17 mbpd in the Base Scenario in 2020. This would imply an increase of consumption (and build-up of infrastructure, etc.) of 6.5% per annum over 30 years. It is questionable if the LDC's will be able to afford the capital expenditure necessary for building up the gas infrastructure without assistance. *Figure 4* compares

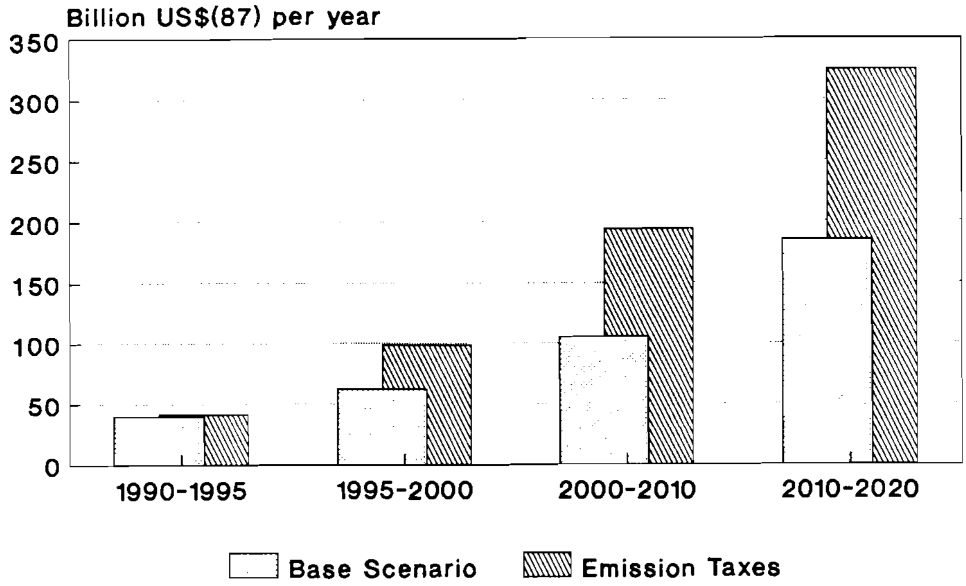

Figure 4: LDC's: investments in gas infrastructure, in 10^9 US$(87) per year.

the annual investment requirements for the LDC's in the Base Scenario and the case with emission taxes. The cumulative investments required between 1990 and 2020 are 3400 billion US $(87) in the Base Scenario versus 5900 billion US $(87) in the case with emission taxes. By 2020, natural gas use in the LDC's would be 2 times the present use of this fuel in the OECD.

The conditions, under which the necessary gas infrastructure could be developed, would have to be investigated further. The models of the LDC regions include present technology for gas transmission and distribution. They take care of the fact, that new grids in newly built areas are cheaper and that initial investments are relatively lower than adding low density areas to an existing system, but other effects, like reduction in pipe-laying costs due to newly developed technologies (that are not yet available now) are not included in the analysis. Such measures would, however, be necessary to avoid the extremely high investment figures derived in the model run with emission taxes.

Pollutant emissions in the OECD countries can be reduced considerably compared to the Base Scenario: The level of SO_2 emissions is one quarter of the present level, the reduction of CO_2 and NMVOCs amounts to 35% by the year 2020. For all the other pollutants the reduction is between 40 and 50% (see *Figure 5*).

For the LDC's the picture is completely different: only CO and SO_2 can be reduced and kept at levels lower than 1990. The emission of NO still increases by 17%, NMVOCs by 55%, methane by 30% and, worst of all CO_2 more than doubles compared to the level of 1990!

4.3 Comparison of carbon dioxide emissions

Figure 6 compares total emissions of CO_2 for the two model runs: in the Base Scenario CO_2 emissions in the OECD area are stabilized, the overall growth of 1.3% per annum over the next 30 years is contributed by the LDC's. In the run with environment taxes CO_2 emissions in the OECD area are reduced considerably, but this reduction is more than compensated by the growth of CO_2 emissions in the LDC's, the overall level of CO_2

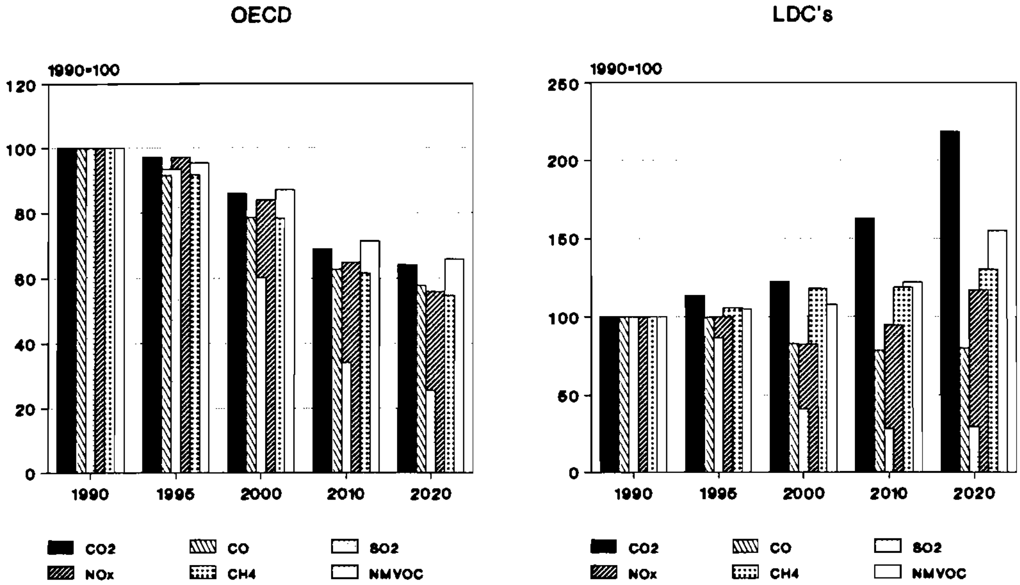

Figure 5: OECD and LDC's: pollutant emissions, Emission Taxes, index (1990=100).

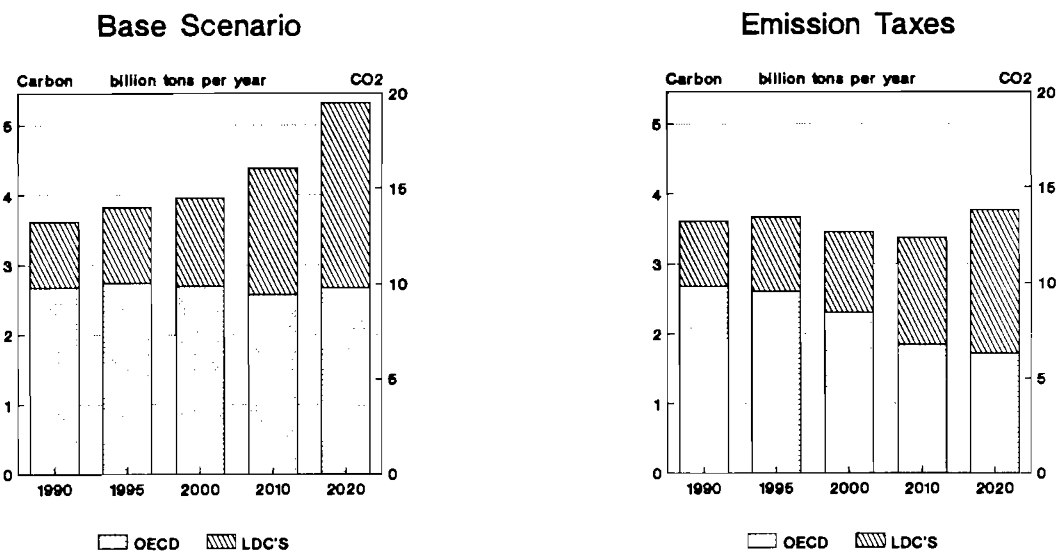

Figure 6: Comparison of runs: emissions of CO_2, in billion tons.

declines slightly up to 2010, but by 2020, caused by the higher economic growth, a level higher than in 1990 is reached again.

Figure 7 directly compares the annual CO_2 emissions in the two model runs with the 1990 figures for the OECD, LDC's and the sum of the two regions (Total). Stable CO_2 emissions in the Base Scenario in the OECD countries are turned into a reduction of 35% by 2020 by the environment taxes, while the increase by a factor of 2.8 in the LDC's is reduced to the more moderate increase of a factor of 2.1. In total, the CO_2 emissions of the two regions grow by nearly 50% by the year 2020 in the Base Scenario; environment taxes soften this development nearly to stabilization, but with an increasing tendency after 2010.

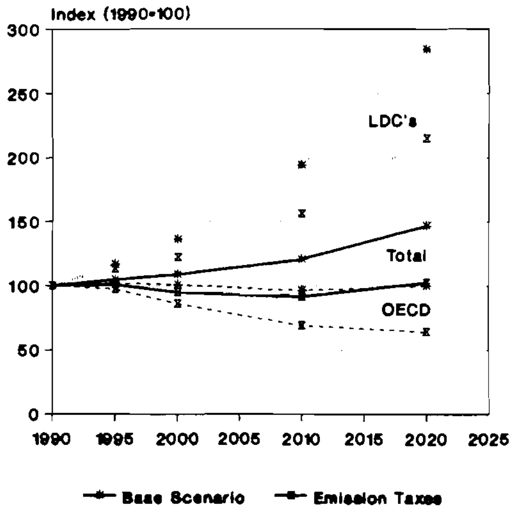

Figure 7: Comparison of runs: emissions of CO_2, index (1990=100).

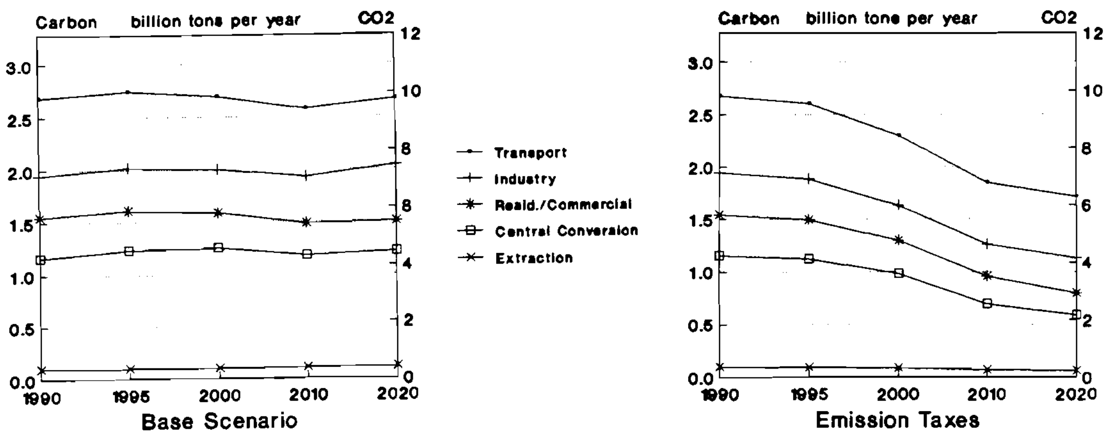

Figure 8: OECD: comparison of sectoral CO_2 emissions, in billion tons.

4.4 Sectoral carbon dioxide emissions

The contribution of the different sectors to the emissions of CO_2 is displayed in *Figure 8*: it compares CO_2 emissions from resource extraction, central conversion of energy and energy use in the residential and commercial sectors, in industry and for transport for the Base Scenario and the Environment Taxes Case. Generally the highest share of CO_2 is accounted for by central conversion, mainly power generation (around 40%). The transport sector is the next largest producer of CO_2 with 27% in 1990, followed by the industrial and the residential/commercial sectors with roughly 15% each.

In the Base Scenario the major trend is a reduction of the contribution of the transport sector from presently 27% to 24% by 2020, which is caused by the improving quality, i.e., hydrogen content of the fuels when aviation penetrates stronger into passenger and freight transport[6], and of the residential/commercial sectors, which would emit 27% less CO_2 in

[6]Final energy use for transport purposes is constant in the scenario, increases in the passenger- and ton-kilometers are offset by efficiency improvements in the equipment used.

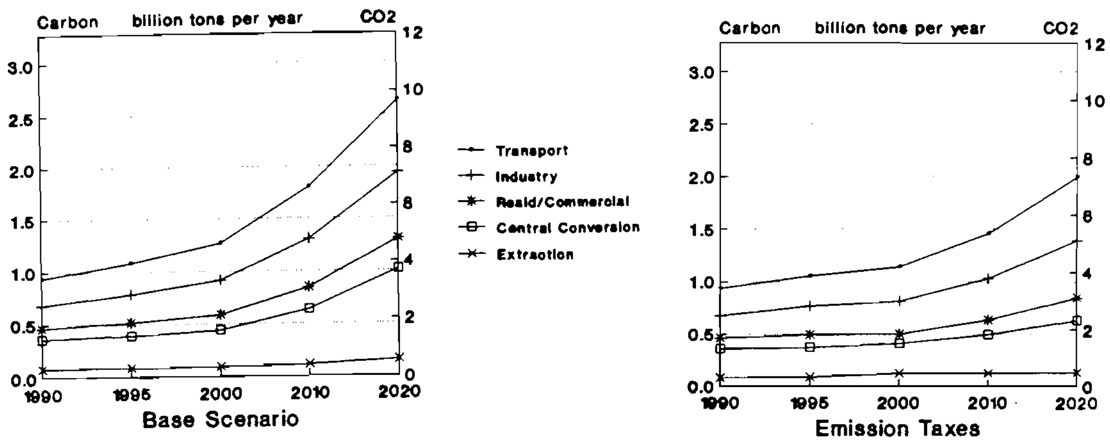

Figure 9: LDC's: Comparison of sectoral CO_2 emissions, in billion tons.

2020 than in 1990. Final energy use in the residential/commercial sectors grows at an annual average rate of 0.4% per year, the reduction of CO_2 emissions is caused by the change in the energy carriers used: coal is nearly phased out, the contribution of liquid fuels is reduced from 25% in 1987 to 10% in 2020. The use of natural gas is constant, the remaining gap is covered by electricity, district heat and renewable sources of energy.

CO_2 emissions from central conversion grow slightly over the model horizon; the increase in overall electricity production is offset by the growing contribution of nuclear energy and the use of combined heat and power production. The major growth of CO_2 emissions comes from the industrial sectors, which, in 2020, emit one third more than today. Besides the growth in industrial final energy use the reasons for this development are the increased use of heavier oil products, that are not used for electricity generation any more, a slight increase in the use of coal and a reduction in the use of renewable sources of energy.

In the model run with emission taxes overall CO_2 emissions can be reduced by 35% by 2020 (22% in 2005). The major reductions come from central conversion and the residential/commercial sectors, that reduce their emissions of CO_2 by roughly 50% by 2020. Emissions of the transport sector are, compared to the Base Scenario, only reduced slightly, industries emit 16% less CO_2 than today or 37% less than in the Base Scenario in the same year.

LDC's CO_2 emissions take an exponential growth path in the Base Scenario: from presently 3.4 billion tons they grow to 5.6 billion tons by 2005 and further up to 7.3 billion tons in 2020, an average growth rate of 2.6% per annum (see *Figure 9*). The shares contributed by the different sectors show a higher contribution of the industrial sector (due to a higher share of coal and a much lower share of electricity in the fuel mix), and a considerably lower share produced from central conversion (also due to the lower consumption of electricity). CO_2 produced during fuel extraction is, due to the high OPEC oil and gas production, higher than in the OECD area. Over the next 30 years all sectors show considerable growth, the highest increases come from central conversion (an effect of electrification) and from industry (due to a 3-fold increase in industrial final energy use), which increase by a factor of three. Emissions from extraction "only" double, the residential and commercial and the transport sectors emit roughly 2.8 times more CO_2 than today.

Environment taxes change the picture: by 2005 38% more CO_2 is emitted than today (compared with 63% in the Base Scenario), by 2020 emissions grow by a factor of 2.1 (compared with 2.8). However, the tendency towards exponential growth is preserved, although at a less steep slope. Also here a relatively high reduction can be reached in central conversion (40% less than in the Base Scenario), followed by the residential/commercial sector (24% less). All other sectors reach a uniform reduction of about 15% compared to the Base Scenario.

4.5 Investments

Stabilization of total CO_2 emissions in the OECD plus LDC areas at present levels up to 2020 (compared to an increase of 50% in the Base Scenario) can be reached through measures justified by tax levels of US $46 per ton of CO_2 (equivalent to US $170 per ton of carbon) in the OECD area and half that value in the LDCs, in conjunction with taxes on other pollutants. However, such measures require an enormous investment effort. *Figure 10* compares the annual investments in the two regions[7] of the case with with emission taxes with the Base Scenario[8]. While the Base Scenario investments of both regions grow steadily between 1995 and 2020 (1.6% annually for the OECD and 5% per year for the LDCs), emission taxes disrupt this development: starting 1995 investments increase considerably. Between 1995 and 2000 investments in the case with emission taxes are 35% higher than in the Base Scenario for the OECD. In the LDCs the increase occurs more gradually, starting with 14% around 1995 and growing to 70% by 2000. One of the causes for the high increases in the LDCs is that, in addition to the measures taken in the OECD, like subsitution of clean fuels for coal or investments in conservation measures, also technologies for reducing SO_2 and NO_x emissions, which are already applied widely in the OECD area, have to be introduced. Emission taxes entail a relative reduction in all pollutants considered, and present environmental standards in the LDCs are low: a lot of relatively cheap measures are available, which will be applied even at the lower tax level chosen for the LDC regions, thus increasing investments considerably in a transition period.

After 2000, total investments in both regions are reduced to levels below the Base Scenario. This can be attributed to the generally lower energy consumption levels and could well be offset by higher investments in more efficient equipment or conservation measures, which are not included in the investment figures.

In the longer run, chnages in investments in energy supply stay minor for the OECD area (a reduction of 2% up to 2010 and 4% up to 2020). The 15% reduction of energy consumption roughly offsets the investments required for cleaner energy supply. The LDC area shows more substantial reductions in investments: 3% up to 2010 and 10% up to 2020. The supply of 12% less primary energy, together with the investments in emission reductions induced by the tax level of US $23 per ton of CO_2 (CO_2 emissions are 25% below the Base Scenario compared to a 35% in reduction the OECD) seem to be feasible with 10% lower investments after an extraordinarily costly transition time.

[7]The figures for OPEC were omitted from the analysis because oil trade and construction of new oil production infrastructures distort the picture.

[8]The figures include all investments in the energy conversion chain from resource extraction up to energy utilization by the various users. They do not include investments in conservation or restructuring measures to reduce useful energy consumption.

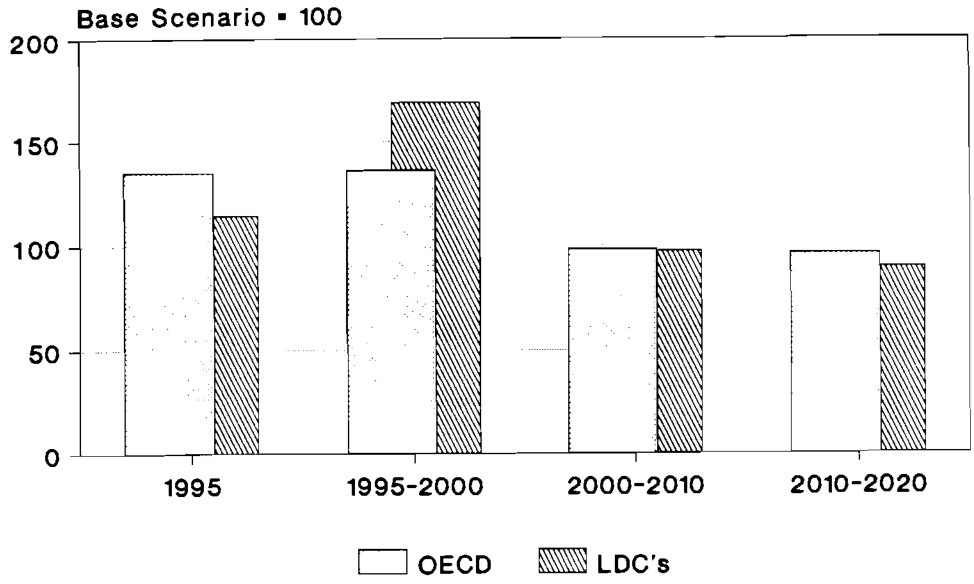

Figure 10: Comparison of runs: annual investments, index (Base Scenario = 100).

5 Final Remarks and Outlook

The UK Department of the Environment (1990) states that carbon emissions from fossil fuel use amounted to 5.5 Gt[9] carbon in the year 1987, which is equivalent to 20.4 Gt of CO_2. Thereof 48% are emitted in the OECD, 16% in the LDC's and 36% in the Centrally Planned Economies (CPE's). The "Toronto Target" of reducing overall emissions of CO_2 by 20% by the year 2005 (compared to 1988 levels) seems to be infeasible, given the results of our analysis and keeping in mind the current energy situation in the world. For example, the Soviet Union faces severe problems in oil production and a decreasing public acceptance of nuclear energy, both resulting in the necessity to at least maintain present levels of coal use, and the expressed policy towards enhanced use of coal in the People's Republic of China will result in a sharp increase in CO_2 emissions.

Another hampering factor will be the unwillingness of industrialized nations to contribute their share to such reduction measures: While the federal body of ministers of Germany, as first of the seven leading industrialized nations, who postulated such measures on their summit meeting in Paris, 1989, already decided on a target of a 25% reduction of CO_2 emissions by 2005 (Energiewirtschaftliche Tagesfragen, 1990), other industrialized nations like the USA, Japan and the UK seem to be unwilling to take measures for reducing their CO_2 emissions (Bley, 1990). According to responses to a letter sent by IEA to all governing board members, they are "still examining the need for, or the scope of, actions to deal with the greenhouse gas problem."

The analytical tool applied to the analysis described in this paper could be instrumental in evaluating potential paths to reach given emission levels for different pollutants. Additional technologies to reduce the net emissions by extracting the chemicals from the atmosphere and technologies representing improvements that could be reached by additional research could be included. Such investigations could even be extended to the evaluation of tradeable permits, introducing interregional transfers—especially between the OECD area and the developing world—of allowances for CO_2 emissions and determining a "market clearing price" for such permits. Such an analysis would, however,

[9] 1 Gt = 1 gigaton = 10^9 tons

require a longer time horizon and thorough analyses of the potential to improve current technology or introduce new, cleaner technologies or abatement measures.

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